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Comprehensive modelling for approaching the Kyoto targets on a local scale

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Abstract

This study aimed to evaluate the effectiveness of the MARKAL comprehensive model in the development of coherent medium-term strategies and sound climate protection policies at local level. The local case study (Val d'Agri, Basilicata region, Italy) discusses the possible role of local communities in the achievement of the national objectives derived by the Kyoto Protocol, investigating the traditional sectors responsible for air pollution and providing a full picture of the main energy and material flows. A scenario by scenario analysis was performed to analyse the response of the modelled system to the introduction of an exogenous constraint on carbon dioxide (CO_2) emissions. The main effects are presented with reference to fuel mix, technology choice, real market prices and reduced costs of competing options. The comparison of the solutions obtained for the different scenarios is useful to point out the effects of the CO_2 constraint on the total system cost and on the emission levels of other atmospheric pollutants. A further multiobjective optimisation was performed to analyse the effects of combined environmental constraints (CO_2 and particulate) on the overall system cost as well as in terms of marginal costs.

Keywords: Local energy planning; MARKAL models generator; Greenhouse gases abatement

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1. Introduction

According to EU [1] guidelines, national policies [2] and scientific findings [3–5], a major use of renewable energy technologies may offer a good chance to slow down resource depletion and to diminish environmental pollution, contributing to three fundamental objectives: greater competitiveness, safety energy supply and environmental protection.

These issues are more topical in relation to the necessity of reducing greenhouse gases (GHGs) emissions, as stated by the Kyoto Protocol (KP) which establishes severe emissions limits for 38 industrialised countries. In this framework, the Italian Government agreed to reducing the overall GHGs emissions by at least 6.5% below 1990 levels in the commitment period 2008 to 2012, defining the guidelines for national actions in different sectors [6].

According to the Italian guidelines, the decrease of fossil fuel consumption and the increase of renewable share are considered strategic objectives to be pursued at local scale by researchers, planners and Local Authorities. The main proposed interventions deal with a re-organisation of the productive system and a more effective configuration of energy conversion technologies either on a large or small scale. Therefore, it is necessary to promote synergetic interventions on both the supply and the demand side based on a better use of resources and technologies: e.g. use of high efficient processes which reduce fossil fuels consumption, introduction of renewable sources and fuels with lower carbon percentages, and increase of the energy saving share.

In this framework, it is important to assess the role and the potential market of new technologies, pointing out their main technical, economic and environmental features.

To achieve this goal, energy-technology model generators (such as MARKAL) are a valid support for strategic planning and decision making. They allow the users to describe the technological development of the analysed system and to choose the best available configuration relatively to cost minimisation and environmental effectiveness.

Moreover, these models are based on a comprehensive approach which takes into account input and output flows between the different macroeconomic sectors (e.g. Energy Conversion, Agriculture, Civil, Industry, Waste Management). This allows the exploitation of feedback among the sectors and the identification of 'robust strategies' based on integrated actions, which are stable to the variation of boundary conditions.

In this work, MARKAL is applied to investigate the energy system of Val d'Agri, an area of Basilicata region, which is interesting because of a recent and sudden increase in oil-mining activities. The study aims to estimate the possible contribution of renewable energy sources to the fulfilment of electric energy end-use demand, under the hypothesis of a CO_2 emissions reduction (in compliance with the national KP).

2. The local energy system

Val d'Agri extends over 1860 km^2 from the north-west to the south-east of the Basilicata region (southern Italy), in the middle of the Lucano Apennine, and is crossed by the Agri river. This area consist of 29 municipalities (27 of them belonging to the province of Potenza and two to the province of Matera) grouped in six mountain communities (Lagonegrese, Collina Materana, Camastra Alto Sauro, Melandro, Alto Agri, Medio Agri) with a total of 73 075 inhabitants (12% of the population of Basilicata).

Val d'Agri is an evocative and ecologically intact region from a scenaric and naturalistic point of view, features that led to the establishment of the Natural National Park of Val d'Agri (Italian laws 394/91 and 426/1998). The main economic activities include agriculture (cereal and forage cultivation, breeding and horticulture, olive tree, vine and citrus cultivation), Industry (food and drink, buildings) and, above all, oil-mining activities. As a matter of fact, Val d'Agri represents the largest Italian oil field (with estimated reserves of 420 million barrels equivalent [7]): in 1997 about 11 352 barrels per day of crude (9.5% of the national production) were produced, treated at the Viggiano pilot oil centre and then transported to the refinery of Taranto by tank truck. According to ENI company [8], the drilling of some 30 new wells will lead, in the period 2003–2004, to a daily production of 154 000 barrels whereas the laying of a pipeline will ensure a straight connection between the oil centre and the refinery, located in a neighbouring region.

For local energy planning, an important step in the technical analysis of the analysed system regards the evaluation of energy consumption and the characterisation of energy supply and demand, in the base year [9,10]. In this framework, the energy balance gives an overall picture of the input and output flows, providing an insight

into the initial mix of energy sources, the peculiarities of the end-use segments, the efficiency of conversion technologies and the suitability of distribution networks.

2.1. Energy supply

The Basilicata region imports about 40% of the required electricity from other regions. The endogenous production (1381 GWh) is based on hydropower plants (20%, owned by the National Company ENEL) and fossil-fired power plants (80%, owned by private companies) [11].

The contribution of Val d'Agri to the total regional production is about 11%, mainly produced by the hydropower plants of Gallicchio (113 GWh/y) and Tramutola (1.3 GWh/y). The actual installed capacity can be increased up to about 45 MW, with an extra production of 16.14 GWh/y, building up some mini-hydropower plants [12].

The photovoltaic solar technology is showing great promise and its use is encouraged in Basilicata region by incentives. In Val d'Agri there are 16 photovoltaic plants, which produce electric energy for isolated end-users, with a total installed capacity of 36 kWp. According to the Regional Energy Plan [12] their actual capacity can be increased to 11.6 MWp, with an average production per year of 75 GJ/y.

Moreover, the feasibility of building up a biomass power plant which utilises as renewable fuel the endogenous by-product of forest and agricultural activities, was evaluated. Taking into account the present annual production of forest waste products and grain field residues in the area, the estimated electric energy productivity ranges between 18.56 GWh/a and 21.95 18.56 GWh/a (the latter related to a possible increase of forest waste in future years), under the hypothesis of a conversion plant with an efficiency of 25% and an average low calorific value for biomass of 5 kWh/kg [12].

Table 1 summarises the present contribution of renewable energy sources for electric energy production in Val d'Agri and its possible development.

2.2. Energy demand

The energy demand of Val d'Agri is about 1 683 174 GJ and represents about 5% of the regional energy demand. Industry (Fig. 1a) and residential (Fig. 1b) are the

Table 1
Present and future estimated contribution of renewable energy sources in Val d'Agri

Renewable source in Val d'Agri	Present contribution (GWh/anno)	Estimated future contribution (GWh/anno)
Hydropower plants	116	–
Mini-hydroelectric plants	–	16.14
Biomass plants:	18.56	21.95
–from Forest waste	7.26	21.95
–from Grain Field residues	11.3	–
Photovoltaic plants	0.06	20.78

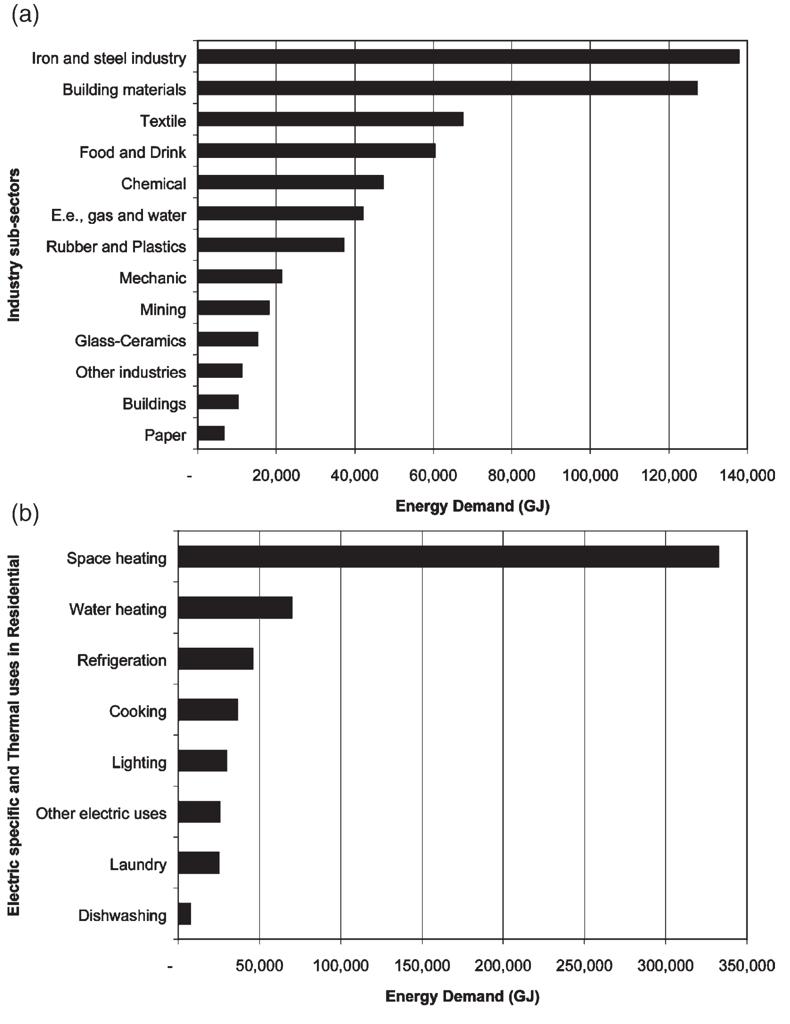

Fig. 1. Energy demands by sub-sectors: industry (a) and residential (b).

most energy consuming sectors, contributing respectively to 36% and 34% of the total energy demand, followed by agriculture (18%) and commercial and services (12%).

Electricity is the most used energy vector (39%), followed by fossil liquids (2% fuel oil, 4% LPG, 16% diesel), gaseous fuels (26% natural gas) and solids (9% firewood, 4% other solids).

Such percentages show that the demand of fossil liquid and natural gas is lower than the average Italian one (respectively 38%, 35%); on the other hand, the case study shows a higher consumption of electricity and solid fuels (national values: 22%, 4.4%) [13].

This preliminary investigation suggests opportunities for substituting traditional technologies with renewable ones in electricity production, to foster a positive effect on the environment and for a more rational use of resources.

2.3. Atmospheric emissions

The amount of pollutant emissions from the analysed system was estimated on the time horizon, according to the CORINAIR methodology [14,15]. CORINAIR emission factors were integrated with EPA emissions factors [16] with regard to the phases of oil extraction and pre-treatment, on the basis of the strategic environmental assessment (SEA) studies on the Val d'Agri oil fields. These studies take into account emissions of several local atmospheric pollutants (CO_2 excluded). Moreover, the contribution of mining activities was evaluated (Fig. 2) taking into account the increasing amounts of oil [8] and the substitution of tank truck transport with an oil pipeline from 2006. It can be noted that the emissions associated with the transport phase are much lower than those produced by the extraction and pre-treatment phases, thus their increase is the most evident factor. The only exception to this trend regards the VOC emissions, which decrease from 24.8 ton/y to 10.4 ton/y due to the activation of the oil pipeline.

On the other hand, oil transport by pipelines, may also generate atmospheric emissions from connection points, valves and damaged sections; therefore it is necessary to monitor these accidents by inspection procedures [17].

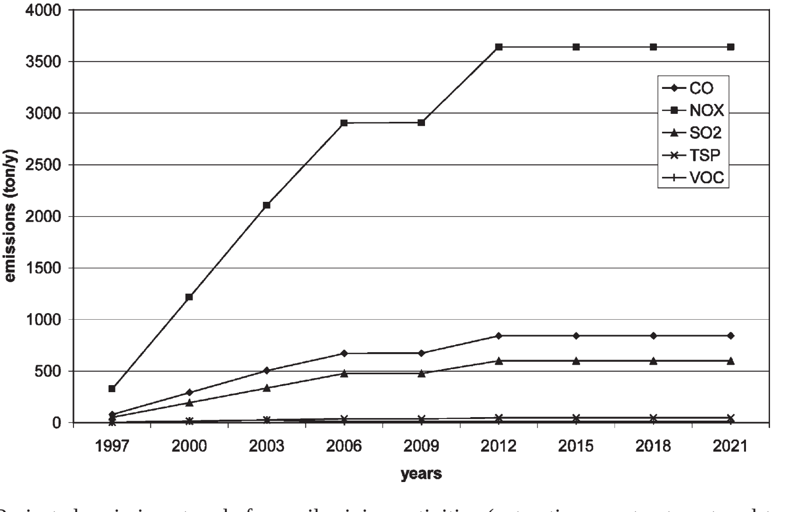

Fig. 2. Projected emissions trends from oil-mining activities (extraction, pre-treatment and transport).

3. Methodology

3.1. The MARKAL models generator

The anthropogenic activities system can be advantageously represented by analytical models, to schematise the complex relationships among human activities and environmental processes, defining a basic common framework for planners and system analysts.

This is important also to manage the uncertainties due to unforeseeable factors, as future development of energy and socioeconomic scenarios, physical boundary conditions, availability of resources and technologies, fuels price, scientific findings and technology developments [18,19].

In this framework a comprehensive modelling approach based on a least cost optimising criterion allows one to perform a multi-objective analysis which is useful to define the limits of the system (carrying capacity [20]), to support the decision making process, to evaluate the feasibility of action strategies and to assess the potential market of new technologies and fuels, both from an economical and environmental point of view [18,21,22].

Among the available comprehensive models generators, MARKAL is the most widespread. MARKAL belongs to the ‘bottom-up’ economic-engineering family of models, and can be applied both for large- and small-scale planning [23–25]. It was developed under the aegis of the International Energy Agency’s (IEA) in the framework of the Energy Technology Systems Analysis Programme (ETSAP) [26] and has been utilised for energy-environmental planning since the early 1980s [27]. In recent years it has also been implemented for the analysis of material flows, to take into account the overall impact of the anthropogenic activities system, which is essential to ensure a correct assessment of suitable strategies for mitigating environmental damage [28–31].

MARKAL allows planners, energy analysts, researchers, environmental experts to generate appropriate models for the specific needs, taking into account differences in time horizon, spatial scale, and technology details. Such features make it a very flexible tool, which can be extensively used to identify cost-effective abatement strategies, performing prospective analysis of systems behaviour under different scenarios, individualising the priorities of different measures and evaluating the effects of regulations, taxes, and subsidies.

The structure of every model generated by MARKAL is based on a Reference Energy and Material System (REMS), which represents energy and material flows between demand and supply sides, crossing demand devices, processes and conversion technologies. Existing and future technologies of supply and demand sides are represented quantitatively by a set of technical (efficiency, life, availability), environmental (emissions factors) and economic parameters (investment, operating and maintenance costs) [9,10]. These characteristics represent the core of the model database.

Some basic work hypotheses must be formulated to set up the reference database for the MARKAL model and to define the possible development of the energy system

relatively to resources availability and socio-economic framework (e.g. length of time horizon and time periods, commodities demand, energy and technological resources availability, fuels prices, etc.). In addition to the basic hypothesis, specific assumptions may be formulated to model different future scenarios and to investigate the system's response to the variation of exogenous parameters (e.g. emissions levels, money discount rate).

Therefore input data tables have a multi-period flexible structure which enables an easy modelling of the technological development and of the variations of boundary conditions, allowing the choice of different levels of data aggregation. The optimising procedure, based on a least cost approach, selects that combination of technologies and fuels that minimises the total energy system cost (the primary function), fulfilling all the exogenous constraints. In particular, starting from a reference database, it is possible to examine a range of future alternative ('scenarios') investigating the effects of changes in boundary conditions (e.g. emissions and legislative restrictions, availability and/or prices of energy fuels, money discount rate, etc.) on the optimised system configuration. In each optimisation run, the model finds out the least expensive combination of technologies to meet those requirements, up to the limit of feasibility (boundary conditions). The obtained values can be plotted as a function of the variable scenario parameters by continuous cost curves (trade-off curves), being therefore possible to estimate the induced variation of the total cost over the whole time horizon. This is of special interest in establishing abatement policies because the trade-off curve and its derivative (shadow prices curve) provide information about the range of the average environmental taxes necessary to achieve a prefixed target of abatement. In particular, the shadow prices of the constrained pollutants define the monetary equivalent of the emissions avoided and can, for example, be used to set the value of an environmental tax. Moreover, the analysis of the reduced costs provides information on the price differences among competing technologies which produce the same commodities, taking into account the availability of technologies and the market boundaries. Reduced costs are zero for the marginal technologies, negative for the upper bounded resources which are utilised up to the maximum (the model would like to use it over the limit), they are positive for the resource not utilised or lower bounded.

3.2. The demand sectors and the REMS of MARKAL—Val d'Agri (VdA)

An aggregated representation of the Reference Energy and Material System (REMS) for Val d'Agri is given in Fig. 3, which describes (from the right to the left) end-use demands, technologies and energy sources: the grey boxes represent the renewable energy technologies and insulation packages. The network of technologies reproduces the actual configuration and takes into account the future technological development (efficiency improvement, introduction of renewable technologies, changes in waste management options).

The REMS of MARKAL-VdA among the supply side includes the existing power plants (conventional thermal fossil fuelled, hydroelectric, photovoltaic plants) and, according to the regional energy plan [12], mini-hydroelectric and biomass plants

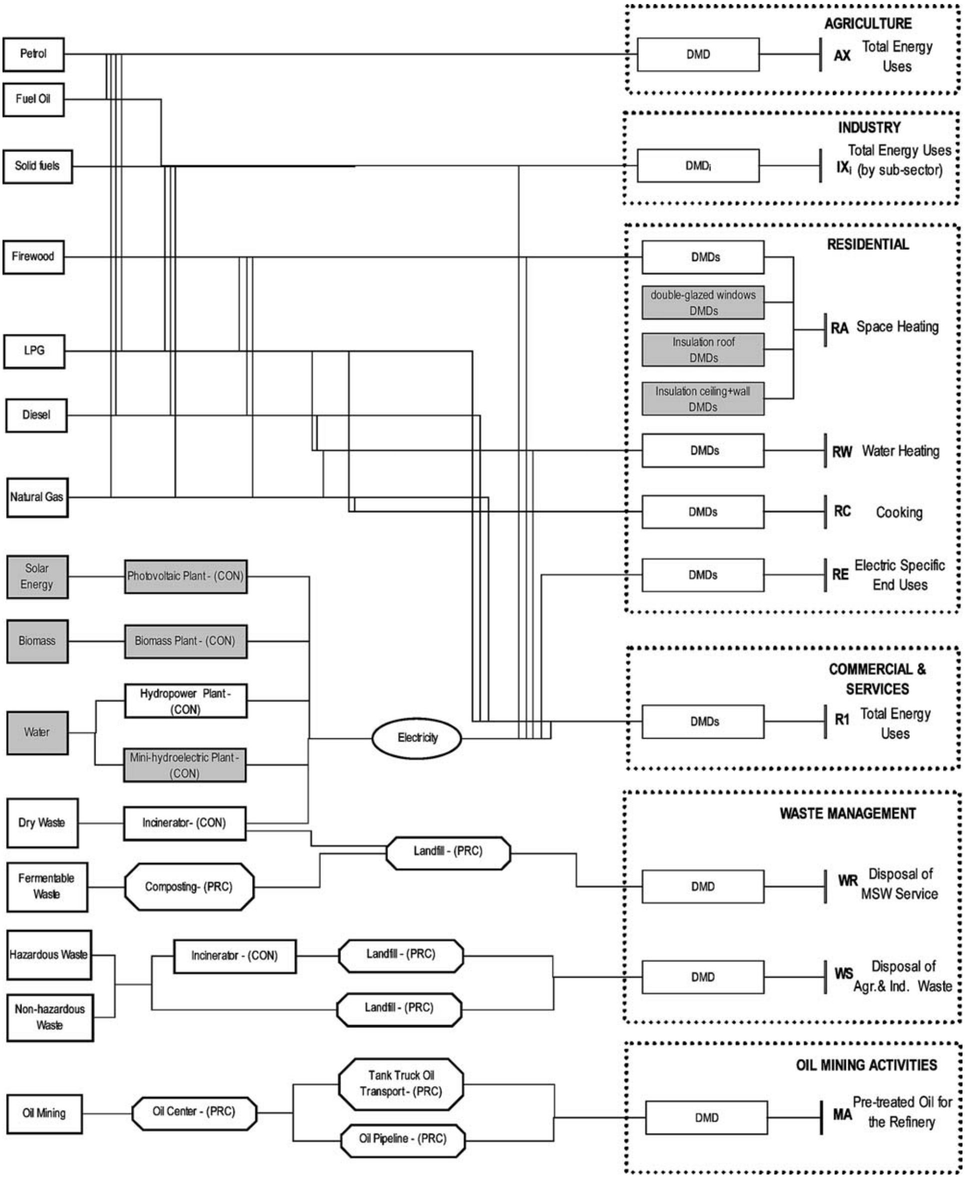

Fig. 3. Schematic representation of the REMS for MARKAL-VdA.

were added to the technology network, starting their activity from 2003, whereas an increase of photovoltaic share is also considered. An input flow was also provided to model the import of electric energy and its related emissions (occurring outside the investigated area).

To take into account the recent national laws on waste management [32], landfills

are progressively substituted by an integrated system of technologies aimed to waste valorisation and pollution prevention. The waste handling system for municipal solid waste (MSW) is based on the following actions: separate collection of secondary raw materials (paper/cardboard, plastics, glass, aluminium cans, etc.), mechanical pre-treatments (by rotary drum screening), combined use of three main processes: incineration with energy recovery of the ‘dry’ fraction resulting from screening, aerobic stabilisation of the ‘moist’ fraction and high-quality composting of selected biodegradable matter. Incineration with energy recovery was considered as the alternative option to landfilling also for nonhazardous/hazardous solid wastes from agriculture and industry.

According to the Provincial Waste Management Plan [33] no incinerators will be built in Val d’Agri. Thus, a dummy incinerator was added in the REMS of MARKAL-VdA to take into account the emissions due to waste burning occurring outside the area.

In the implemented model, the standard demand sectors (agriculture, residential, commercial and services, industry and waste management) were modelled using a different level of detail in relation with data availability and the possible use of renewable technologies.

An aggregate ‘black-box’ representation is used for agriculture, industry and commercial and services to take into account energy flows and waste flows from these sectors and to facilitate a more detailed desegregation, according to further planning issues.

Industry, was divided, as in the regional energy balance, in twelve sectors (food and drink, paper, chemical, mining, building materials, mechanic, iron and steel industry, textile, glass–ceramics, other industries, buildings, electric energy, gas and water), briefly represented in Fig. 3 by a unique box and labelled through the index ‘i’.

The energy demand of residential takes into account thermal uses (space heating, cooking, water heating) and electric obliged uses (i.e. lighting, use of electrical appliances, general services for households). Demand devices were modelled considering an implicit improvement of the efficiency of electrical appliances and boilers. Three insulation packages on existing buildings were analysed: double glazed windows, roof insulation, ceiling and outside wall insulation. With reference to national average data [34], each one of the first two options may induce a 20% potential reduction of energy consumption for space heating, whereas ceiling and outside wall insulation gives a −25% contribution.

3.3. Scenario assumptions

As concerns the work hypotheses and scenario assumptions, in the MARKAL-VdA case study energy demand was considered constant, because there is not a significant demographic growth and the increase of commodities demand is balanced by a better use of resources and by technology efficiency improvement.

Time horizon spans from 1996 to 2023 being divided into nine time periods, each one of 3 years. The money discount rate is 4%. The basis year is 1997: it is the

reference year for estimating the energy consumption and for discounting the costs of energy activities.

An unconstrained business as usual scenario (BAU) was thus defined to analyse the optimised natural trend of the development for the actual energy system.

Three scenarios with increasing constraints on CO_2 emissions were also defined: CO2-1%, CO2-2.3%, and CO2-4%, which make effective the prefixed CO_2 reduction (1, 2.3 and 4%) on the whole time horizon. These targets give rise to higher abatement target, respectively 8.6, 10 and 12%, comparing the 1997 emission level of CO_2 to the average yearly amount calculated on the reference period for the KP (2008-2012).

This behaviour is emphasised in Fig. 4, which shows a comparison between the national target (−6.5%) and the reduction actually achieved by the analysed scenarios in the same time period.

4. Scenarios analysis

The main results obtained by the optimisation of the analysed scenarios are discussed in detail in the following paragraphs, exploiting the fundamental implications of different strategies on the technological configuration and on the environment.

4.1. Impacts on the technological configuration

The optimisation of the VdA energy system shows a general decrease of energy consumption due to the best utilisation of the available resources (energy and

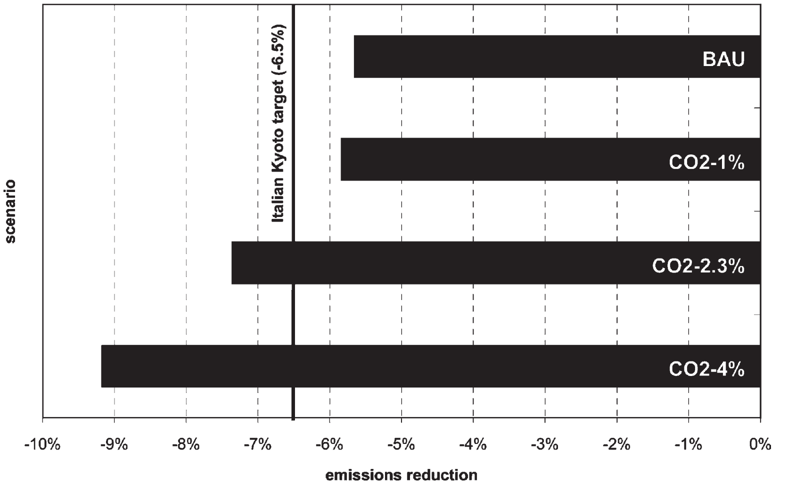

Fig. 4. Comparison of emissions reduction in different scenarios with the Italian Kyoto target.

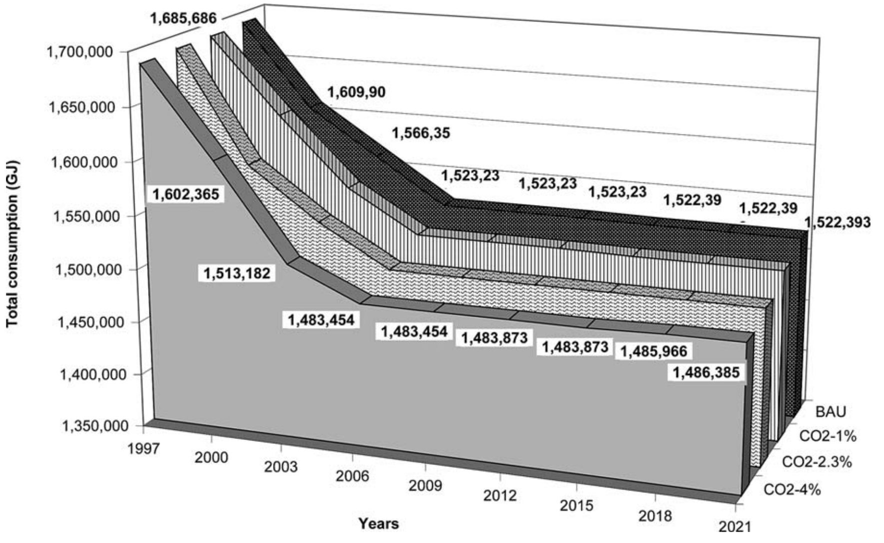

Fig. 5. Energy consumption in the four examined scenarios.

technologies). In particular, as shown in Fig. 5, the total consumption may be reduced from 10% (BAU scenario) up to 12% in the CO2-4% scenario.

Due to the exogenous constraint on CO_2 emissions, the total discounted system cost (on the overall time horizon) increases from the basic value of 862 millions of Euro to 972 millions of Euro (trade-off curve of Fig. 6), with a 13% average increase.

Taking into account the total emission levels in the different scenarios, the average costs of CO_2 reduction is about 224 Euro/ton for the BAU scenario and 262 for CO2-4% scenario. These values are comparable with the average Italian costs (60 Euro/ton CO_2 [35]), which are estimated imposing a weaker constraint on CO_2 emissions (half of the national KP target).

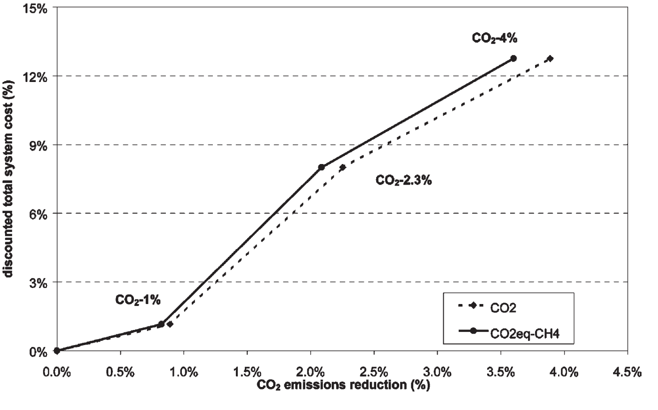

Fig. 6. Total discounted cost vs. CO_2 and $CO_{2\text{-eq}}$ abatement percentages.

The optimised fuels mix, both in the BAU and CO2-4% scenarios, shows many remarkable differences respect to the actual situation (Figs. 7a and 7b). In particular, in the BAU scenario the use of several fossil fuels is strongly decreased (LPG −46%, natural gas −12%) as well as electricity use (−9%), whereas biomass is utilised from the third time period. In the CO2-4% scenario a higher reduction is observed in natural gas use (−31%) whereas biomass and electricity consumption increase respectively 68 and 9%.

These trends are better explained looking at the optimised technology choice. Obviously, the increasing constraint on CO_2 emissions fosters the choice of renewable technologies and energy-saving packages. This implies that, in the conversion

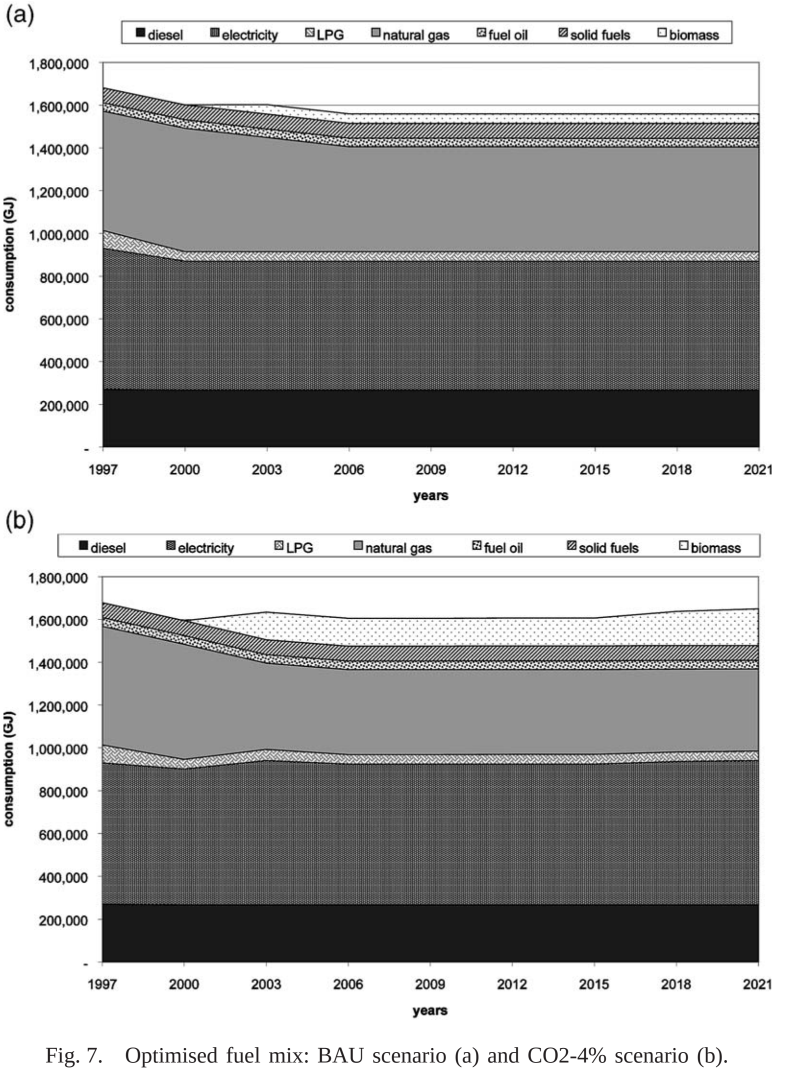

Fig. 7. Optimised fuel mix: BAU scenario (a) and CO2-4% scenario (b).

sector, there is a greater use of the biomass plant and of hydroelectric, with the activation of mini-hydro plants. Photovoltaic remains stable, because of its high investment costs, being far from the marginality level even at the higher CO_2 abatement target. Fig. 8 shows the reduced costs of the analysed renewable power plants. It can be noted that biomass plant is the most convenient technology in all the scenarios examined (being zero its reduced costs), mini-hydro plants become marginal only in the CO2-4% scenario, whereas photovoltaic is even the most expensive technological option and needs suitable incentives or strong environmental constraints to increase its actual share.

As concerns residential, more efficient combined natural gas boilers take the place of diesel and LPG boilers. Energy-saving packages are not used in the BAU scenario because their investment costs are not fully compensated by money saving coming from the decrease of operating expenditures. Nevertheless, these options are often chosen in the presence of a constraint on CO_2 emissions.

In particular, the CO2-1% scenario is characterised by the use of double-glazed windows (the cheaper package), whereas thermal insulation of roofs, ceilings and walls is chosen only when the CO_2 abatement percentages increase (respectively in the CO2-2.3% and CO2-4% scenarios). This behaviour is emphasised by comparing the reduced costs of the three insulation packages in the different scenarios (Fig. 9).

As concerns the waste management system, landfilling of non-pre-treated waste is obviously the cheapest option, but its use is prevented from 2003, in achievement of the Ronchi law [32]. As a consequence, the obliged use of such an integrated waste management system, fosters electric energy production from waste incinerating.

Fig. 10 shows the reduced costs of waste processing technologies, comparing the landfilling of untreated waste to its incineration with final landfilling (as concerns hazardous and non-hazardous agricultural and industrial wastes) and to an integrated

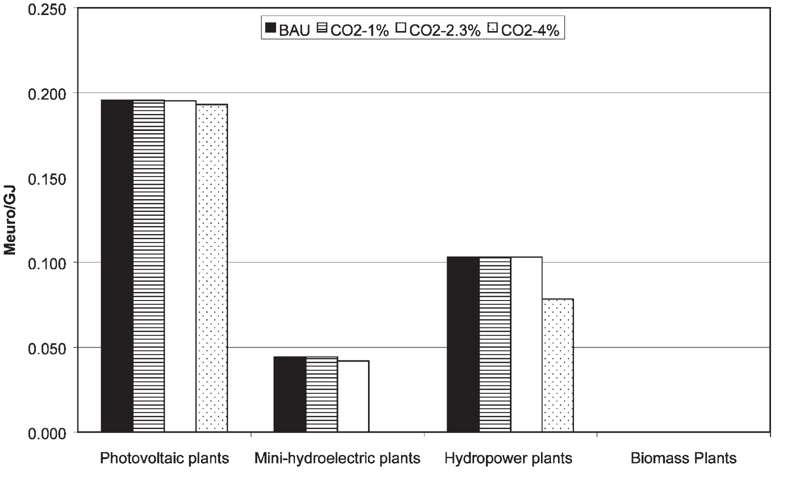

Fig. 8. Reduced costs of renewable power plants.

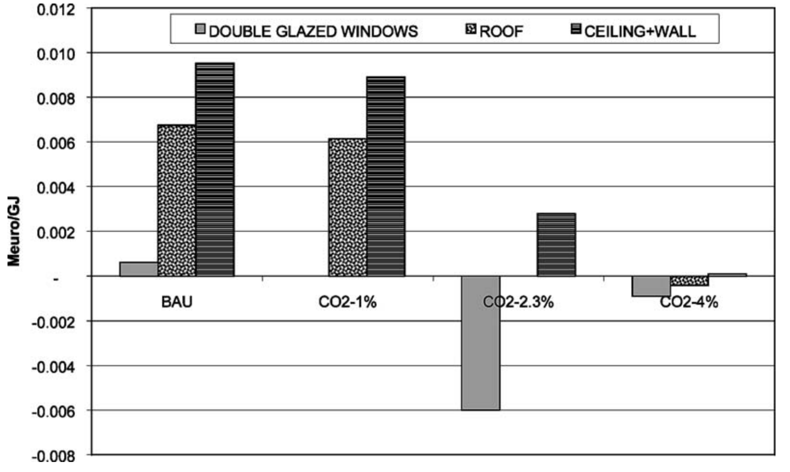

Fig. 9. Reduced costs of insulation packages for existing buildings.

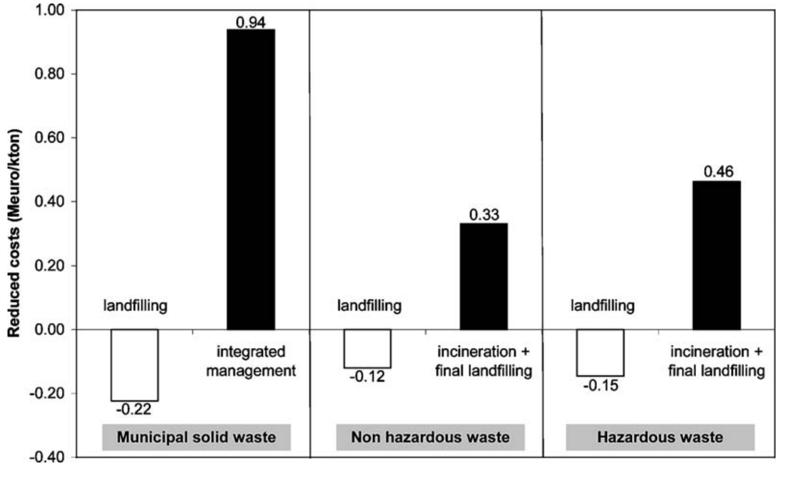

Fig. 10. Reduced costs of waste processing technologies.

waste management system. In all the three cases it can be noted that landfilling of untreated waste (the cheapest option) is characterised by negative reduced costs, due to the presence of a constraint on landfill availability, from 2003. The integrated waste management system for municipal solid waste (MSW) is characterised by the highest reduced costs. The difference with respect to the waste management system of hazardous/non-hazardous wastes can be explained, noting that the management of MSW involves more waste processing technologies and is therefore more expensive than the simple incineration, considered for other waste types.

4.2. Environmental impacts

The constraint on CO_2 emissions fosters the utilisation of renewable energy sources, with a general positive effect on the environment. Nevertheless, changes in technology configuration may induce unpredictable effects on those pollutants not directly influenced by a consumption decrease. Therefore, to characterise the environmental effects of CO_2 constraints, the behaviour of six main air pollutants was investigated (carbon monoxide, CO; methane, CH_4; nitrogen oxides, NO_x; sulphur dioxide, SO_2; total suspended particulates, TSP; volatile organic compounds, VOC). The analysis was concentrated on the emissions trends of residential, conversion and waste management, discussing also their contribution to the total emissions (calculated taking into account also the contribution of agriculture, industry, commercial and services).

Moreover, the emissions of CO_2 equivalent were compared to the total CO_2 emissions to emphasise the role of the waste management system, which has a great influence on methane emissions.

In Table 2 the emissions of the base year (1997) are compared to the average annual values estimated for the BAU and the CO2-4% scenarios, with particular reference to conversion technologies, waste management and residential sectors.

Relatively to electricity production (conversion technologies), the activity of the biomass plant induces an huge increase of CO, VOC and TSP emissions. This is more evident in the CO2-4% scenario, in which the biomass plant is utilised at the highest level and the activation of energy saving measures is not sufficient to compensate this increasing trend.

Changes in waste management options and the increase of separate collection targets produce important variations in CO_2 equivalent emissions: in the first two time periods, landfills are the basic technology whereas the incinerator starts its activity from 2003. Consequently, pollutant emissions from landfilling (VOC and CH_4) decrease from the third period (when the only source of such emissions is represented by final landfills). On the other hand, the activation of an incinerator causes the emissions of the typical products of combustion (CO, NO_X and SO_2) and an increase of TSP, which decreases on the time horizon as long as the target of separate collection increases.

As concerns residential, the most widespread technology is represented by natural gas boilers, which have the lowest CO_2 emissions factors. However, the increase of natural gas boilers causes an increase of CO, TSP and VOC emissions, which is compensated by the positive contribution of energy saving options. This effect is more evident in the CO2-4% scenario, in which there is a small decrease of all the combustion pollutants.

As concern the total average emissions of all sectors it can be noted that there is a remarkable increase of CO (+33%), TSP (+56%) and VOC (+6%) on the time period 2001–2022, whereas the emissions of other pollutants remain almost stable.

These trends suggested performing an optimisation of the system with combined constraints on CO_2 (as in the CO2-4% scenario) and TSP emissions (determining stepwise the minimum feasible level on the time horizon). The resulting case CO2-

Table 2
Comparison of VdA emissions between BAU and CO2-4% scenarios

	Conversion technologies			Waste management			Residential			All sectors		
	[ton/year] 1997	Average [ton/year] (2001–2022)		[ton/year] 1997	Average [ton/year] (2001–2022)		[ton/year] 1997	Average [ton/year] (2001–2022)		[ton/year] 1997	Average [ton/year] (2001–2022)	
		BAU	CO2-4%		BAU	CO2-4%		BAU	CO2-4%		BAU	CO2-4%
CO	20.57	284.91	373.86	374.74	373	4.5	373.86	374.74	373	998	1878	2489
CO_2	77566	70971	14762.64	15918.63	10638	4669	14762.64	15918.63	10638	149 130	137 637	132 124
CH_4	0	0	0	0	0	331	0	0	0	2244	0.23	0.23
NO_x	61	54	12.2	13.22	11	18	12.2	13.22	11	739	3381	3390
SO_2	92	93	4.39	4.2	4.2	9	4.39	4.2	4.2	267	709	709
TSP	3.96	47.23	17.12	17.38	17	0.9	17.12	17.38	17	102	180	280
VOC	3.05	43.51	29.15	29.32	29	10	29.15	29.32	29	1444	1472	1565

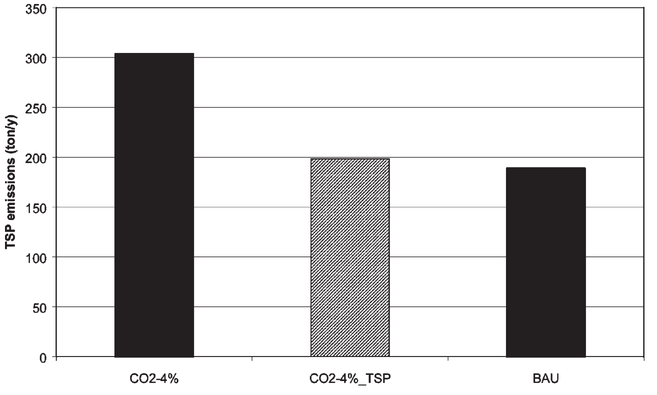

Fig. 11. Average emissions of TSP in different scenarios.

4%_TSP is characterised by a 32% reduction of the TSP emissions (4802 ton, on the overall time horizon) compared to the CO2-4% scenario.

Fig. 11 shows a comparison among the average annual TSP emissions amounts estimated for the scenarios BAU, CO2-4% and CO2-4%_TSP.

The stabilisation of TSP emission in the CO2-4%_TSP case is mainly obtained by reducing the use of biomass plants and increasing mini-hydro and photovoltaic (PV) plants utilisation (Fig. 12).

As a consequence, the reduction of particulate is obtained with a 9% increase of the total cost respect to the CO2-4% scenario: from 972 MEuro (CO2-4% scenario) to 1070 MEuro (CO2-4%_TSP case).

The shadow prices of carbon dioxide in the different scenarios were also compared

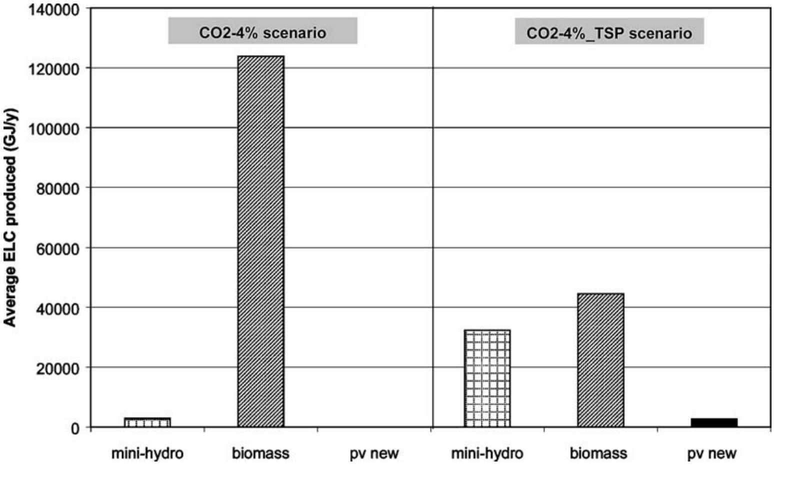

Fig. 12. Average electric energy production by renewable technologies.

(Fig. 13) to get a monetary quantification of the costs to be paid per unit of CO_2 reduced. It can be noted that the value obtained in the CO2-4%_TSP case (0.026 MEuro/ton) is more than double that obtained in the CO2-4% scenario (0.011 MEuro/ton). This is essentially due to the activation of photovoltaic plants that, as previously shown, have very high investment costs. Moreover, in the CO2-4%_TSP case the shadow price of TSP can also be analysed, which is 0.56 MEuro/ton.

5. Conclusions

This paper deals with a local scale application of MARKAL model generators to examine the possible paths towards greenhouse gases emissions reduction on a local scale, according to the national Kyoto Protocol (KP) commitments, and their effects on the trend of other local pollutants.

The implemented model provides a dynamic representation of the main macroeconomic sectors of a local scale energy system, with particular attention to electricity production, mining activities, waste management and residential end-uses. In the examined system, renewable energy sources may play a key role in environmental protection strategies. Therefore the feasibility of their implementation was carefully evaluated, with particular reference to the features of the analysed area (Val d'Agri, Basilicata region, Italy) and to the existing regional energy plan.

Several runs of MARKAL model were performed to identify the minimum cost solutions in a base unconstrained scenario as well as in CO_2 constrained scenarios. In this way it was possible to define a new configuration of the local system for the achievement of the national KP target (−6.5%).

The results show that the investigated energy system can achieve a consistent reduction of CO_2 emissions (−5.8%, scenario CO2-1%) improving the efficiency of end-uses devices in residential, introducing low cost insulation package (double-

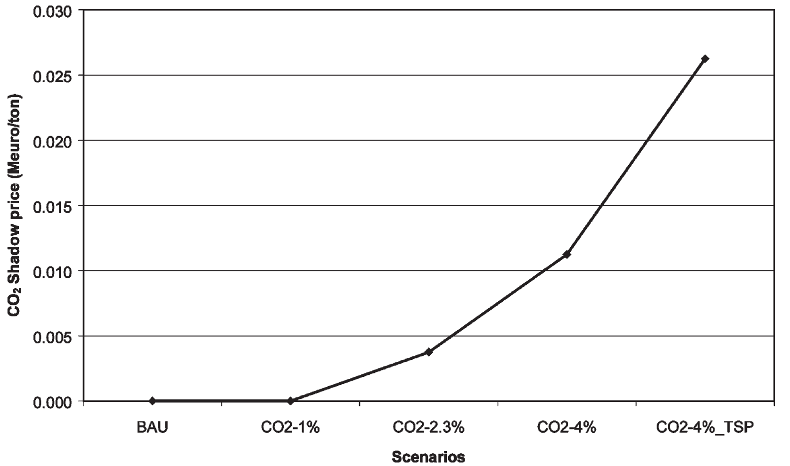

Fig. 13. Increase of the average values of CO_2 shadow prices in different scenarios.

glazed windows) in existing buildings, and activating a biomass power plant. The national KP objectives are reached in CO2-2.3% and CO2-4% scenarios, where the optimised energy system is built up with a greater contribution of renewable conversion technologies (a larger use of the biomass plant and the introduction of mini-hydroelectric plants) and other insulation packages for existing households.

The CO2-4% scenario, is nevertheless characterised by the highest emissions of particulate. Therefore, there were studies of the effects of a combined constraint on TSP and CO_2 emissions. The optimal solution obtained in this case noted that to reduce both TSP and CO_2 emissions (respectively 32% and 4%) it is necessary to reduce the use of the biomass plant and increase mini-hydro and photovoltaic plants share.

The overall results showed evidence that, a sustainable configuration of the system, must be determined by taking into account combined constraints on pollutant emissions, to avoid an increase of those emissions which are not sensitive to CO_2 emissions decrease.

The local scale results are in agreement with those obtained from national studies, showing that the achievement of the KP targets is particularly onerous in systems with a low pro capita carbon intensity where more efficient technological options are largely utilised. Thus, to reduce the actual CO_2 emission levels it is necessary to introduce more expensive options such as photovoltaic.

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